Boron Concrete for Active Formation of Lithium as Mitigation of Neutron-Induced Expansion and Passive Neutron Absorption

Lead PI: Christopher Ferraro, University of Florida

Team Members: James Baciak (UF), Hasan Charkas (EPRI), Eric Giannini (RJ Lee), Calvin McCall (CEC), Jerry Paris (UF), Ashish Patel (UF), Carl Pro (RJ Lee), Kyle Riding (UF)

Novel concrete admixtures for enhanced neutron radiation shielding and resistance to RIVE-assisted ASR

Total project cost:	$1.2M
Current Q / Total Project Qs	Q9 / Q12

TINA-Cement
Annual Meeting
October 13 & 14, 2021

The Team

Christopher Ferraro – PI

Dr. Ferraro is an expert in in mass concrete, alternative supplementary cementitious materials, and concrete mixture design and evaluation.

Jim Baciak – Co PI

Dr. Baciak has extensive experience with characterization of gamma-ray spectroscopy, detector testing, as well as development and analysis of sampling techniques.

Kyle Riding – Co PI

Dr. Riding is an expert in concrete mixture design, durability testing, early-age structural behavior, microstructural characterization, and novel cementitious systems.

Jerry Paris

Dr. Jerry Paris is an expert in concrete mixture designs implementing alternative supplementary cementitious materials with a background in cement hydration chemistry and durability experimentation.

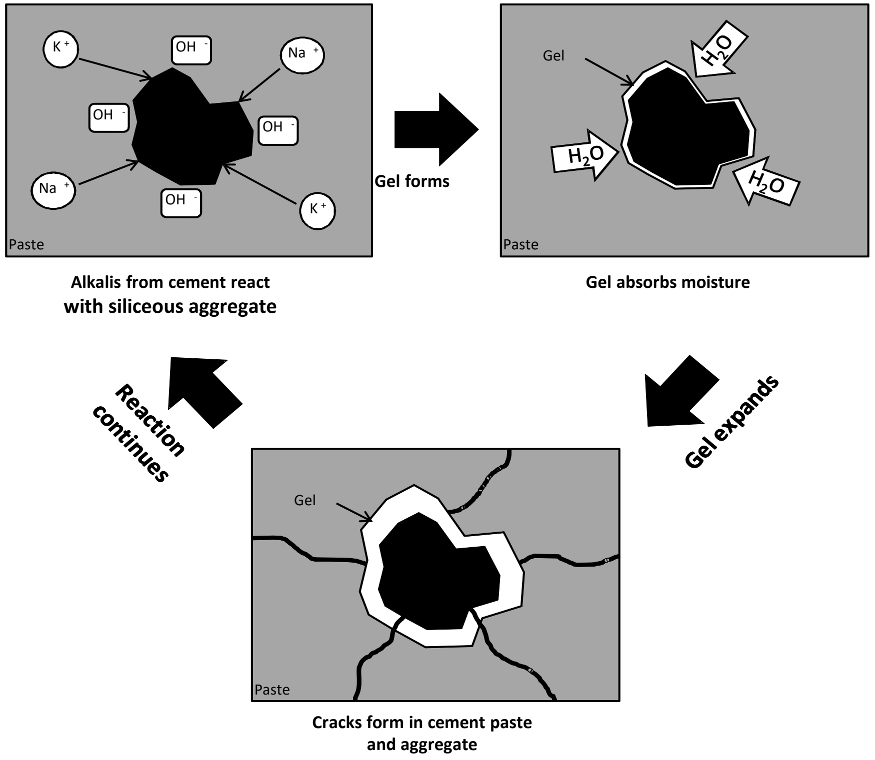
Ashish Patel

Mr. Patel is leading all of the physical experimentation in the cement and concrete labs at the University of Florida.

years of experience.

UF UNIVERSITY of FLORIDA | RJ LEE GROUP DELIVERING SCIENTIFIC RESOLUTION | EPRI ELECTRIC POWER RESEARCH INSTITUTE | Concrete Engineering Consultants, Inc. | arpa·e CHANGING WHAT'S POSSIBLE

Problem: ASR in Aging Nuclear Power Plants

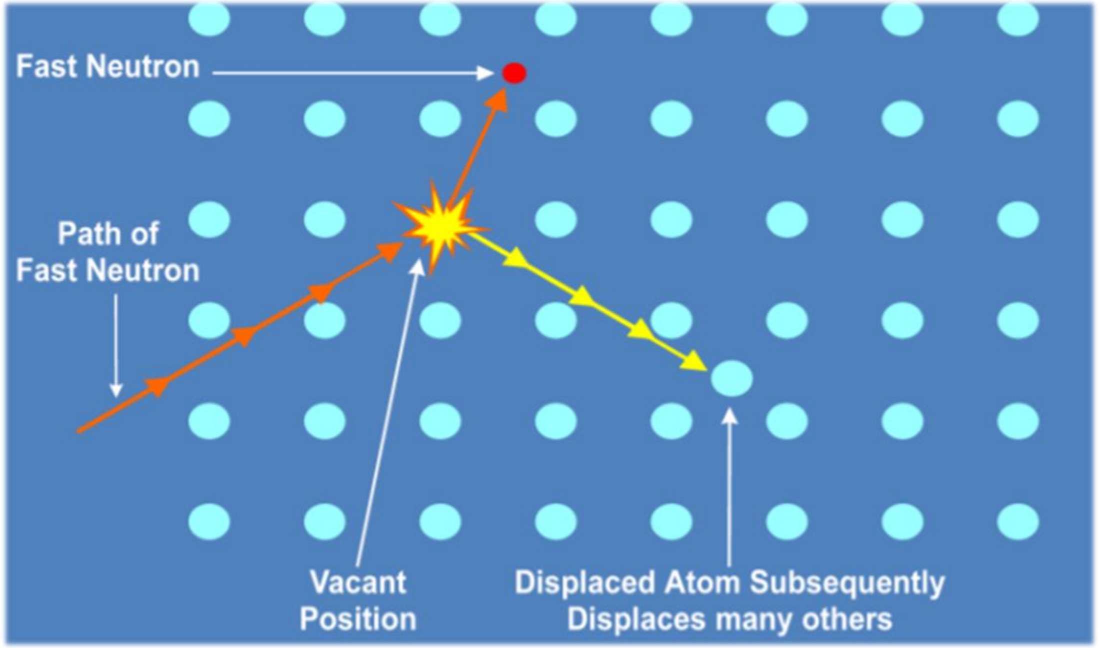


Kreitman, K., 2011, *U.T. Theses and Dissertations*, 148 pp.

Map Cracking at Seabrook

Potential Cause: Neutron Irradiation and ASR

- RIVE-assisted ASR is a neutron fluence-driven phenomenon
  - Collisions with energetic neutrons induce lattice disorder in silicate minerals and causes aggregates to swell (i.e., RIVE)
  - Siliceous aggregate reactivity increases as a function of RIVE



Walters, L. et al. 18th *International Symposium on Zirconium in the Nuclear Industry*

Design Methodology

Application of new technology is dependent on use case:

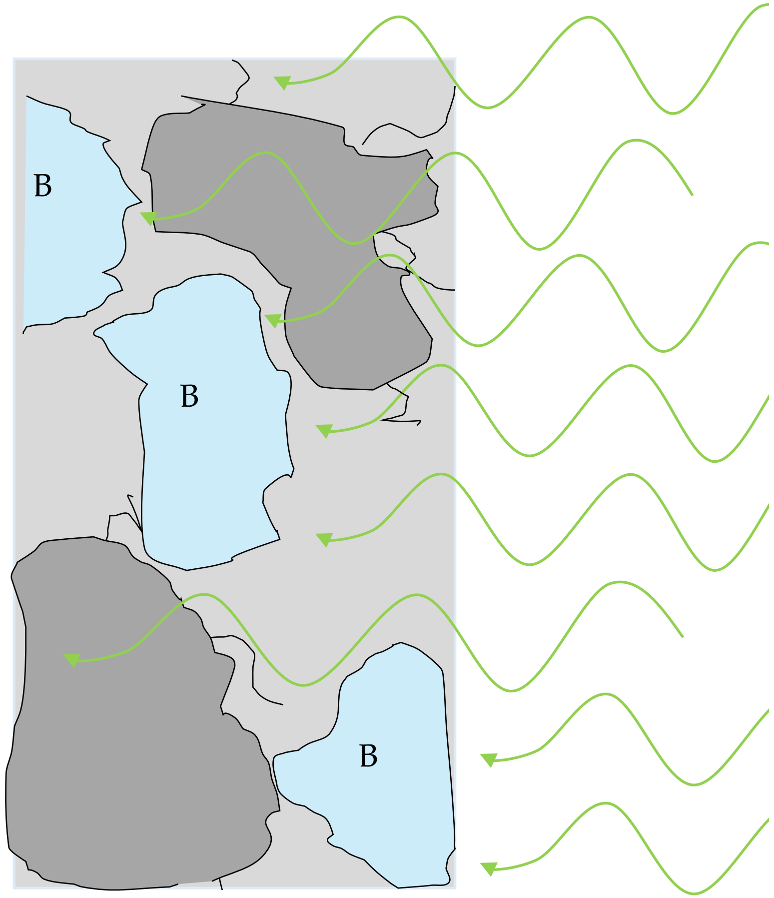
New Construction

Retrofit – Service Life Extension

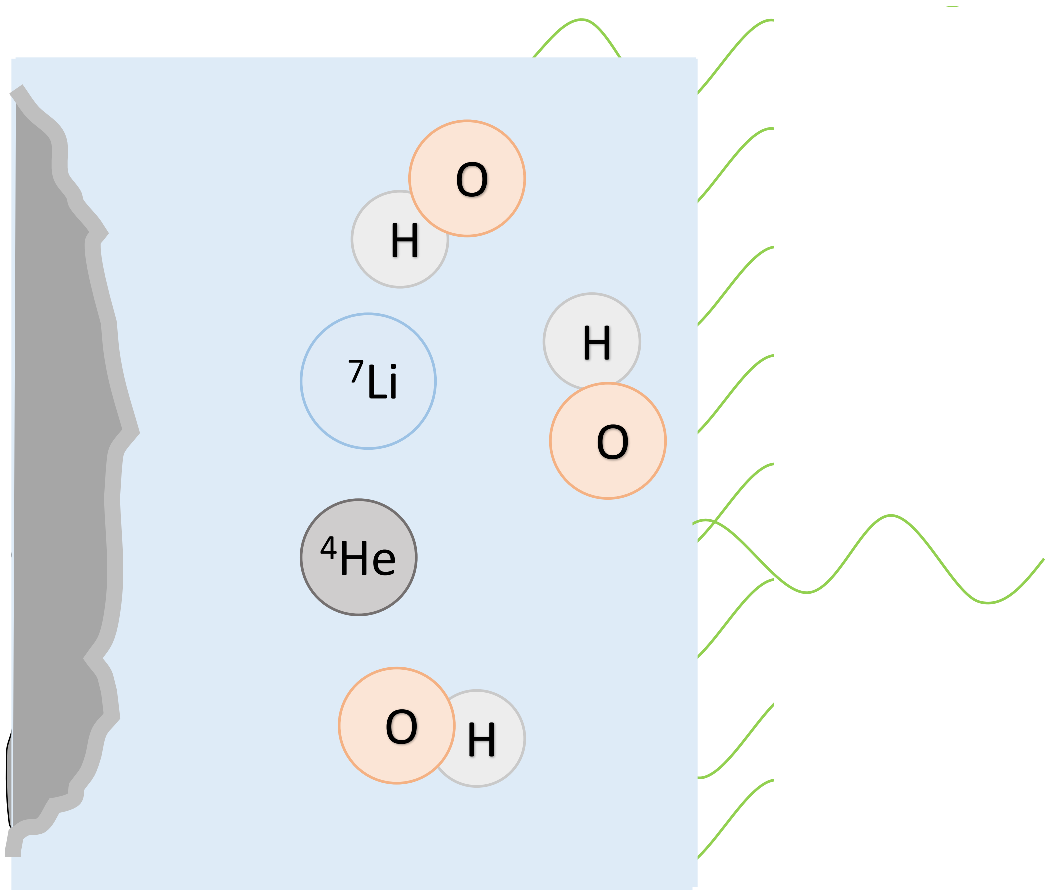
Provides combined neutron shielding and ASR mitigation

Provides highly efficient thin shielding to halt further damage from service life extension

New Construction Solution: Finely Dispersed Boron Admixture



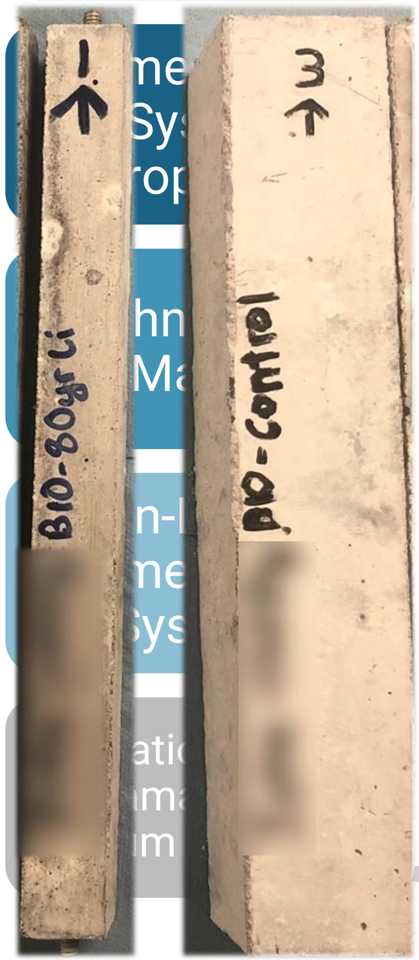
Cross-section of concrete with boron and silicate aggregate



Cross-section of concrete with finely dispersed boron in paste

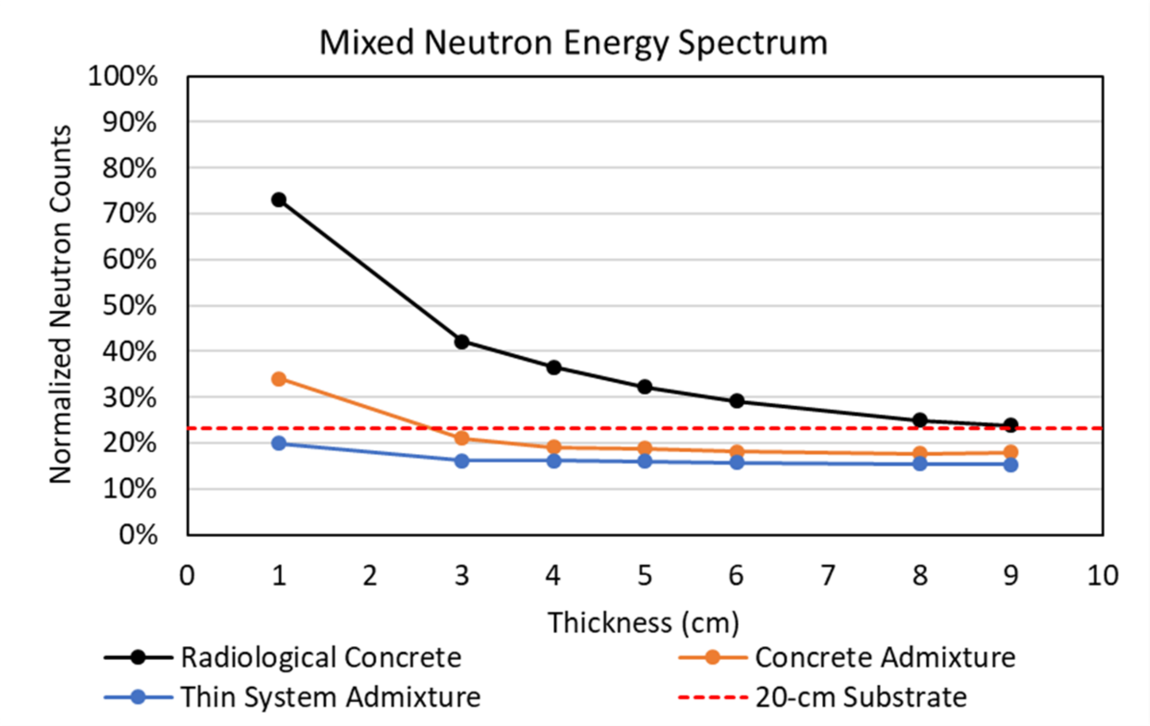
Project Objectives

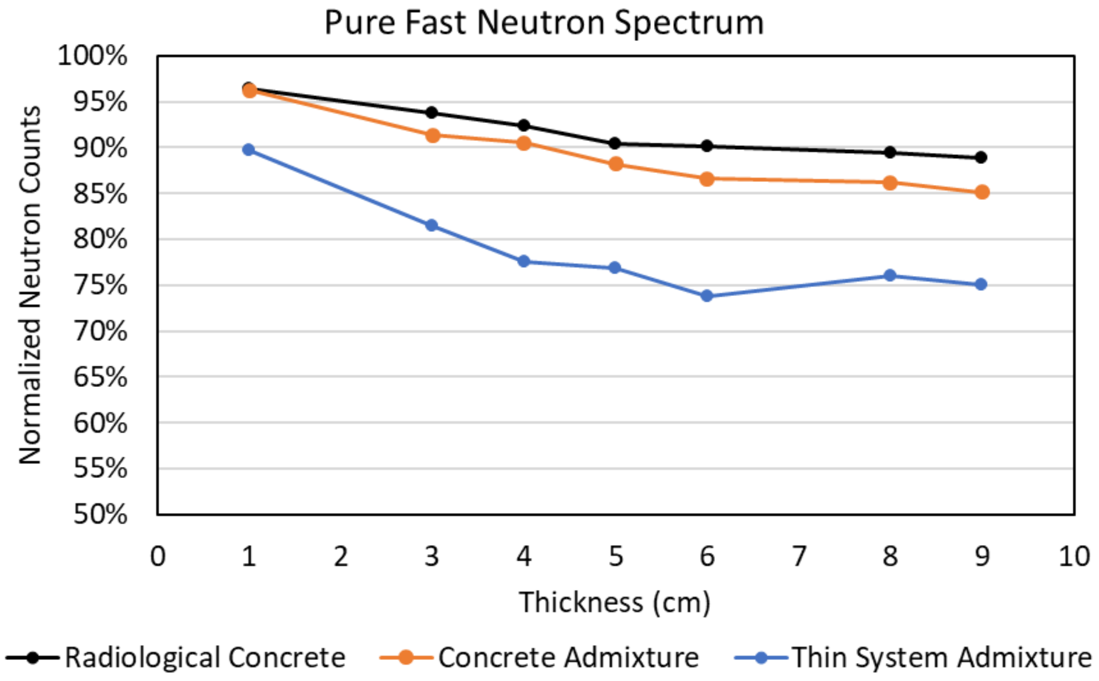
Alkali Silica Reactivity Mitigation



- Specimens to be irradiated in UFTR
  - Exposure conditions: thermal and fast neutron fluences of ~10^{18} neutrons/cm^2
  - Replicate specimens exposed to same temperature-time history
    - Goal is to differentiate microstructural changes due to irradiation and temperature effects
- Petrographic examination
  - Boron transmutation releases relatively large amounts of localized energy
  - Important to characterize the type and extent of damage due to transmutation
- Lithium detection using atom probe tomography and dynamic secondary ion mass spectroscopy
  - If lithium is detectable, these tools will help determine its quantity and distribution within the irradiated specimens
  - Absorbed dose measurements due to thermal and fast neutrons using UFTR

Neutron Shielding Efficiency





- Performance of concrete and thin system admixture is similar under a mixed neutron energy spectrum
- 1 cm mortar w/ boron admixtures equivalent to 20 cm radiological concrete

admixture under purely fast neutron flux

- Thin system enhances rate of thermalization and, thus, the effective neutron capture efficiency

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Challenges and Risks

- Unresolved challenge:
  - Unknown how microstructural damage due to boron transmutation into lithium translates to the macroscale
  - Longer-term irradiation or irradiation under high flux may be necessary to adequately determine damage propagation in systems with boron

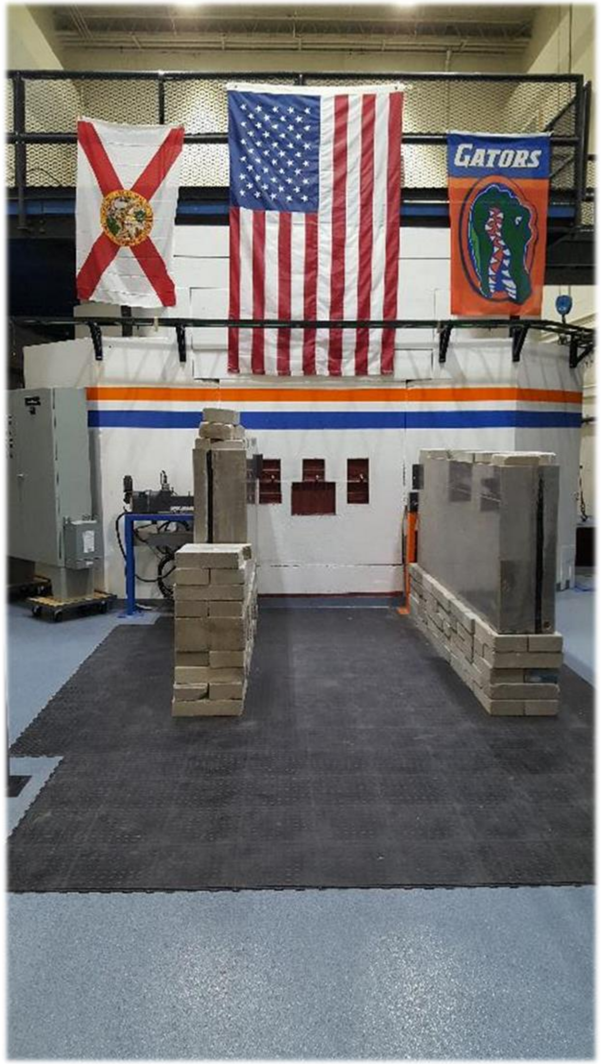
- Resolved challenges:
  - Boron is less effective at neutron capture at higher neutron energies
    - Modifications to boron admixture significantly enhances neutron capture efficiency
  - Limited access between reactor vessel and biological shield for effective retrofit application
    - Thin system admixture can significantly reduce shield size while maintaining high shielding efficiency

Potential Partnerships

- UFTR is a 100 kW (1.8 x 10^{12} n/cm^2-sec) reactor that can offer
  - Sample Irradiations
  - Neutron Activation Analysis
  - Neutron Beam Port Use
  - Real-time Neutron Radiography
  - Detection System Use

- RJ Lee Group – microscopy and petrography (optical/SEM/EBSD), analytical chemistry, failure analysis, material characterization

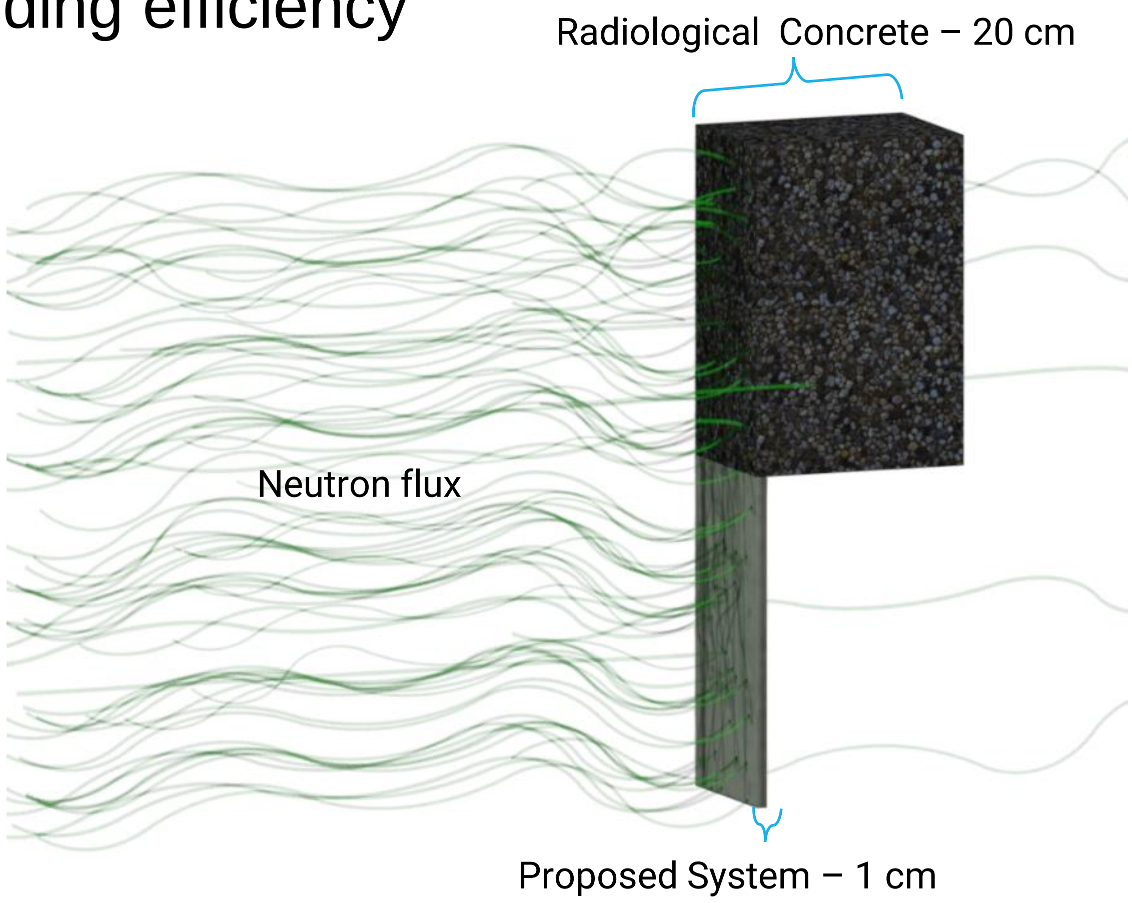
- Team composition is very broad: academia, industry, electric power industry funded research



Summary Slide

- Admixtures designed for concrete and thin shields allow for considerable size reduction without negatively affecting shielding efficiency

- On-going goals include:
  - Assessing irradiation-induced microstructural damage and tracking transmuted lithium in irradiated specimens
  - Establishing a supplier-customer relationship between next-gen NPP OEM and concrete admixture producer



https://arpa-e.energy.gov

Supplemental Slides

How Minerology Characteristics Correlate to Expansion Test Results

- Petrographic Results of Reactive Components of Aggregate Tested

N. Carolina Coarse Aggregate	Texas Sand
Microcrystalline quartz in sedimentary rock – mudstone/siltstone	Amorphous Glass or cryptocrystalline from volcanics (rhyolites and dacites, pumice) Strained Quartz (granite) Cryptocrystalline Quartz (chert/flint)

- Effect of rock density and porosity, crushing?
- Pessimum effect and/or chemistry of system?
- Lithium mitigation mechanism need further evaluation
- Post expansion mortar bar petrography

Mechanism by which $LiNO_3$ Mitigates ASR

- Mechanism still not well understood
- Amount of lithium nitrate needed to mitigate ASR has been identified as a function of the sodium oxide equivalent of pore solution and generally identified as Li:(Na+K) = 0.74
- The effectiveness of $LiNO_3$ varies with the concrete alkali content and the type of reactive aggregate to counteract (regardless of the aggregate reactivity), and its petrographic nature.
- Most likely mechanism is the reduction/suppression of silica dissolution in the aggregate.
  - Reason unknown, but some indication of a protective shell around certain aggregate limiting dispersion of dissolved silica.

Mortar Bars Examined Post C1260 Testing NC and Tx Aggregate

- Control with 1500 g/m^3 ^{10}B and 1500 g/m^3 ^{10}B and 80 years of transmuted Li
- Expansion correlates with gel formation. More ASR gel and cracking in the Control specimens as compared to the Li dosed.
- Aggregates in the NC samples were cracked with gel within the cracks in aggregate and into the paste. No ASR rims.
- The Texas aggregate showed ASR rims forming around aggregate, especially in the Li as compared with the control.
- All the NC aggregate was crushed while the Tx sand could have naturally sized particles included in the testing.
  - Tx aggregate showed completely reacted chert sand grains with no expansion in the Li samples.
- Observations indicate the silica dissolution of the aggregate, porosity of aggregate, and particle size pessimum effect are likely reason for difference in $LiNO_3$
  - NC aggregate more porous and more silica dissolution was observed.
  - Tx aggregate showed potential pessimum effect and ASR gel rims, and reaction confined within aggregate.

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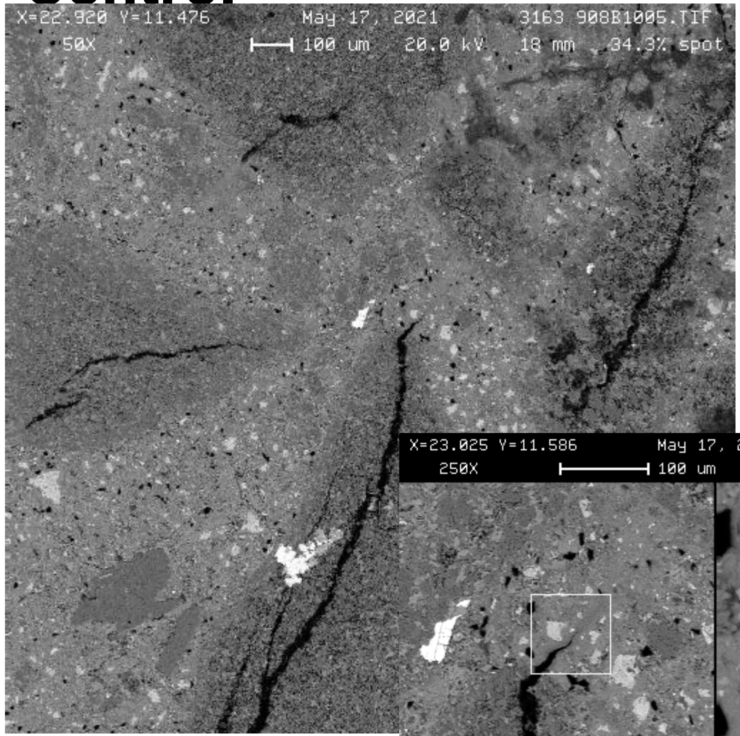
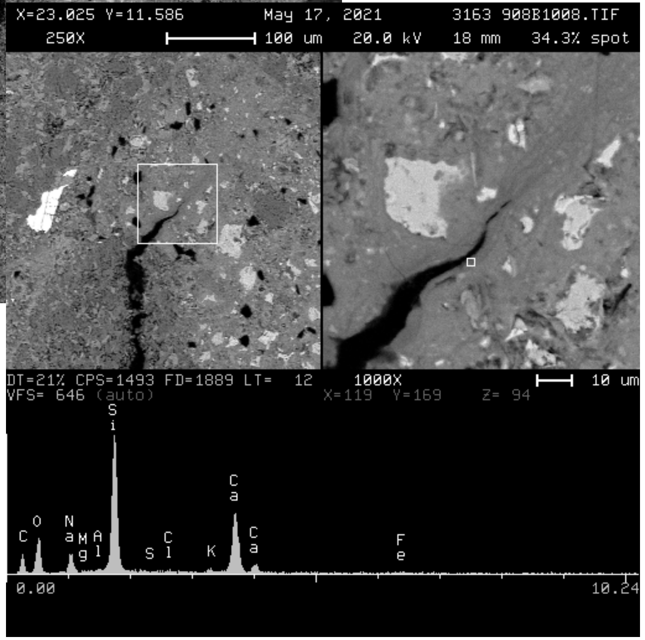
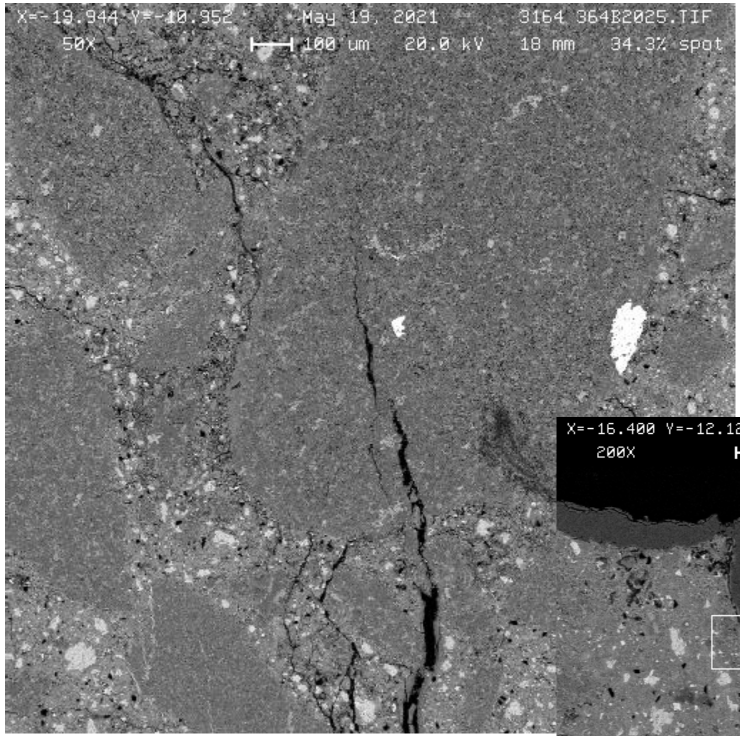
NC Coarse Aggregate

80 year Li

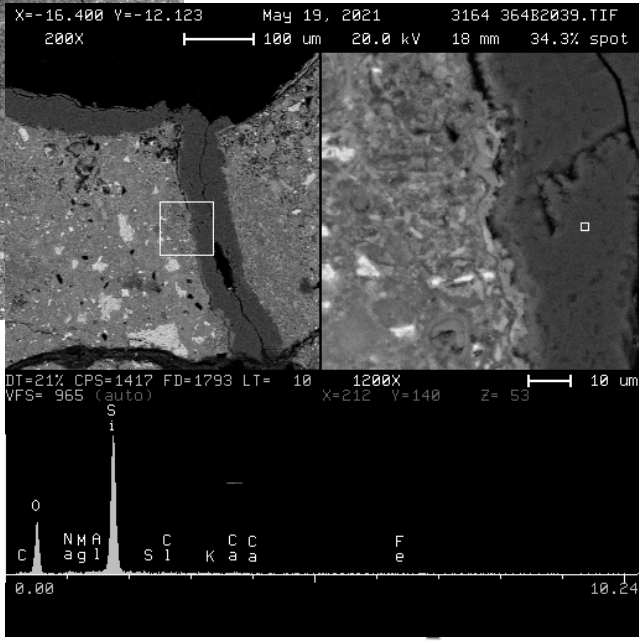
Control





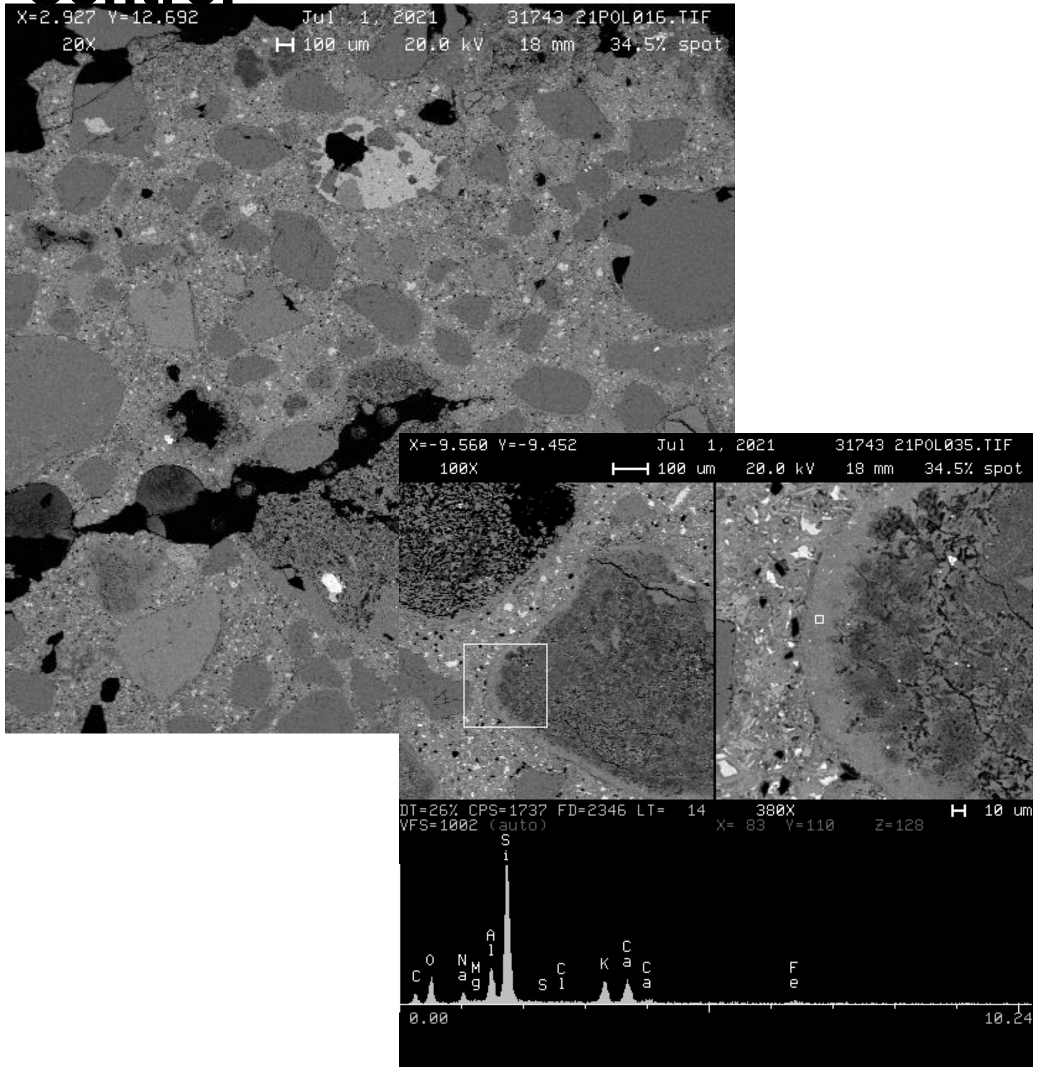


Lithium silicate gel in crack



Texas Fine Aggregate

Control



80 year Li